

**TECHNICAL SUPPORT DOCUMENT FOR  
PROCESS EMISSIONS OF SULFUR  
HEXAFLUORIDE (SF<sub>6</sub>) AND PFCs FROM  
ELECTRIC POWER SYSTEMS:**

**PROPOSED RULE FOR MANDATORY  
REPORTING OF GREENHOUSE GASES**

Office of Air and Radiation  
U.S. Environmental Protection Agency

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## 1. Source Description

The largest use of SF<sub>6</sub>, both in the United States and internationally, is as an electrical insulator and interrupter in equipment that transmits and distributes electricity (RAND 2004). The gas has been employed by the electric power industry in the United States since the 1950s because of its dielectric strength and arc-quenching characteristics. It is used in gas-insulated substations, circuit breakers, other switchgear, and in gas-insulated lines. Sulfur hexafluoride has replaced flammable insulating oils in many applications and allows for more compact substations in dense urban areas. Currently, there are no available substitutes for SF<sub>6</sub> in high voltage applications.

Fugitive emissions of SF<sub>6</sub> can escape from gas-insulated substations and switch gear through seals, especially from older equipment. The gas can also be released during equipment manufacturing, installation, servicing, and disposal.

PFCs are sometimes used as dielectrics and heat transfer fluids in power transformers. PFCs are also used for retrofitting CFC-113 cooled transformers. One PFC used in this application is perfluorohexane (C<sub>6</sub>F<sub>14</sub>). In terms of both absolute and carbon-weighted emissions, PFC emissions from electrical equipment are generally believed to be much smaller than SF<sub>6</sub> emissions from electrical equipment; however, there may be some exceptions to this pattern (IPCC, 2006).

### *a. Total U.S. Emissions*

Emissions of SF<sub>6</sub> from an estimated 1,364 electric power system utilities<sup>1</sup> were estimated to be 12.4 Tg CO<sub>2</sub> Eq. in 2006 (EPA 2008). EPA does not have an estimate of PFC emissions from electric power system utilities.

### *b. Emissions to be Reported*

EPA is requiring electric power systems to report all SF<sub>6</sub> and PFC emissions, including those from equipment installation, equipment use, and equipment decommissioning and disposal.

## 2. Options for Reporting Threshold

EPA evaluated a range of threshold options for electric power systems. These included emission threshold options of 1,000, 10,000, 25,000, and 100,000 metric tons CO<sub>2</sub>e, and nameplate capacity (SF<sub>6</sub> charge) thresholds equivalent to these (713; 7,128; 17, 820; and 71,280 lbs of SF<sub>6</sub>). These equivalencies were developed using historical (1999) data from utilities that participate in EPA's SF<sub>6</sub> Emission Reduction Partnership for Electric Power Systems (Partnership). To determine the nameplate capacity threshold level, the emissions threshold was converted to lbs of SF<sub>6</sub> and divided by the 1999 weighted average annual leak rate (as a fraction of nameplate capacity) of the Partnership. This leak rate was developed by dividing the 1999 SF<sub>6</sub> emissions reported by 42 partner utilities by the nameplate capacity reported by these partners. Partners with extraordinarily high or low leak rates (outliers) were excluded from the analysis. The Partners included in the analysis represented approximately 24 percent of U.S. transmission miles in 2000.

Based on information from the Partnership and from the UDI database, EPA estimates that the 17,820 lbs of SF<sub>6</sub> nameplate capacity threshold covers only a small percentage (10 percent or 141 utilities) of total utilities, while covering the majority (approximately 83 percent) of annual emissions.

A capacity-based threshold permits sources to quickly determine whether they are covered. There have been many mergers and acquisitions in the electric power industry, which could complicate efforts to estimate recent emissions. In contrast, nameplate capacity is generally a known variable. A summary of these threshold options, the total national SF<sub>6</sub> emissions, the total number of facilities, and the number of facilities and emissions falling above each threshold is presented in Table 1.

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<sup>1</sup> The estimated total number of electric power system (EPS) utilities includes all companies participating in the SF<sub>6</sub> Emission Reduction Partnership for Electric Power Systems and the number includes non-partner utilities with non-zero transmission miles. The estimated total number of EPS utilities that emit SF<sub>6</sub> likely underestimates the population, as some utilities may own high-voltage equipment yet not own transmission miles. However, the estimated number is consistent with the U.S. inventory methodology, in which only non-partner utilities with non-zero transmission miles and partner utilities are assumed to emit SF<sub>6</sub>.

**Table 1: Options for Emissions and Capacity-Based Thresholds for Electric Power Systems**

Emission Threshold Level (mtCO <sub>2</sub> e)	Total National SF <sub>6</sub> Emissions (million mtCO <sub>2</sub> e)	Total Number of Facilities	Emissions Covered		Facilities Covered	
			Million mtCO <sub>2</sub> e	Percent	Facilities	Percent
1,000	12.4	1364	12.2	98.3	564	41.3
10,000	12.4	1364	10.87	87.6	158	11.6
25,000	12.4	1364	10.11	81.5	111	8.1
100,000	12.4	1364	5.84	47.1	27	2
Nameplate Capacity Threshold (lbs SF <sub>6</sub> )						
713	12.4	1364	12.19	98.3	578	42.4
7,128	12.4	1364	10.96	88.3	183	13.4
17,820	12.4	1364	10.32	83.2	141	10.3
71,280	12.4	1364	5.95	48.0	35	2.6
Transmission-Mile Threshold (miles)						
47	12.4	1364	12.20	98.3	584	42.8
475	12.4	1364	10.86	87.5	186	13.6
1,186	12.4	1364	8.74	70.4	140	10.3
4,745	12.4	1364	4.53	36.5	34	2.5

EPA also evaluated a threshold based on the length of the transmission lines, defined as the miles of lines carrying voltages above 34.5 kV, owned by electric power systems. Like the nameplate capacity threshold, the transmission mile threshold was developed by dividing the emissions threshold by an emission factor, this one expressing emissions in terms of transmission miles. The emission factor was developed using the 1999 SF<sub>6</sub> emissions reported by 43 partner utilities (representing approximately 24 percent of U.S. transmission miles in 2000), and 2000 transmission mileage data obtained from the 2001 UDI Directory of Electric Power Producers and Distributors (UDI 2001). The transmission-mile threshold equivalent to 25,000 mtCO<sub>2</sub>e is 1,186 miles.

The relationship between emissions and transmission miles, while strong, is not as strong as that between emissions and nameplate capacity. On the one hand, some utilities have far larger nameplate capacities and emissions than would be expected based on their transmission miles. This is the case for some urban utilities that have large volumes of SF<sub>6</sub> in gas-insulated switchgear (GIS). On the other hand, some utilities have lower nameplate capacities and emissions than would be expected based on their transmission miles, because most of their transmission lines use lower voltages and typically use less SF<sub>6</sub>.

### 3. Options for Monitoring Methods

EPA reviewed the 2006 IPCC Guidelines, the SF<sub>6</sub> Emissions Reduction Partnership for Electric Power Systems, the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, the Technical Guidelines for the Voluntary Reporting of Greenhouse Gases (1605(b)) Program, EPA's Climate Leaders Program, and The Climate Registry for this analysis.

These methods coalesce around the three options presented in the 2006 IPCC Guidelines. These include a Tier 1 approach that estimates emissions by multiplying equipment nameplate capacity by default emission factors, a Tier 2 approach that estimates emissions by multiplying equipment nameplate capacity by national emission factors, and a Tier 3 mass-balance approach that estimates emissions based on facility-specific data on SF<sub>6</sub> consumption and nameplate capacity growth.

Although the Tier 1 method is simple, the default emission factors have large uncertainty due to variability associated with handling and management practices, age of equipment, mix of equipment, and other similar factors. Utilities participating in EPA's Partnership have reduced their emission factors to less than the Tier 1 default values. Less than 10 percent of U.S. utilities participate in this program, however, these utilities represent close to 40% of the U.S. grid.

Tier 2 methods use country-specific emission factors, but the Partner utilities have demonstrated through calculating their own utility-level emission factors, that there is large variability (i.e., less than one percent to greater than 35%) in utility-level emission factors across the nation.

The Tier 3 approach is a utility-level mass-balance approach. This method is the approach used in EPA's SF<sub>6</sub> Emission Reduction Partnership for Electric Power Systems. The mass-balance approach works by tracking and systematically accounting for all utility uses of SF<sub>6</sub> during the reporting year. The quantity of SF<sub>6</sub> that cannot be accounted for is assumed to have been emitted to the atmosphere.

The following equation describes the mass-balance approach.

$$\text{User Emissions} = \text{Decrease in SF}_6 \text{ Inventory} + \text{Acquisitions of SF}_6 - \text{Disbursements of SF}_6 - \text{Net Increase in Total Nameplate Capacity of Equipment}$$

where,

*Decrease in SF<sub>6</sub> Inventory* is SF<sub>6</sub> stored in containers (but not in equipment) at the beginning of the year – SF<sub>6</sub> stored in containers (but not in equipment) at the end of the year.

*Acquisitions of SF<sub>6</sub>* is SF<sub>6</sub> purchased from chemical producers or distributors in bulk + SF<sub>6</sub> purchased from equipment manufacturers or distributors with or inside of equipment + SF<sub>6</sub> returned to site after off-site recycling.

*Disbursements of SF<sub>6</sub>* is SF<sub>6</sub> in bulk and contained in equipment that is sold to other entities + SF<sub>6</sub> returned to suppliers + SF<sub>6</sub> sent off-site for recycling + SF<sub>6</sub> sent to destruction facilities.

*Net Increase in Total Nameplate Capacity of Equipment* is the Nameplate Capacity of new equipment – Nameplate Capacity of retiring equipment. (Note that Nameplate Capacity refers to the full and proper charge of equipment rather than to the actual charge, which may reflect leakage.)

This method can also be applied to emissions of PFCs from power transformers.

#### 4. Procedures for Estimating Missing Data

To be accurate, the mass-balance approach requires correct records for all inputs. Partner utilities missing inputs to the mass-balance approach have estimated emissions using other methods, such as assuming that all purchased SF<sub>6</sub> is emitted. However, this method over-estimates emissions. Should the utility be missing records for a given input, it may be possible that the gas or equipment supplier has information in their records for the utility. Alternatively, emission rates from previous years could be applied to the current year, but this approach introduces large uncertainties because emission rates vary from year to year.

#### 5. QA/QC Requirements

QA/QC methods for reviewing completeness and accuracy of reporting include the following.

- Review inputs to the mass balance equation to ensure inputs and outputs to the company's system are all accounted for in all appropriate sections.
- Ensure no negative inputs are entered and negative emissions are not calculated. However, the *change* in storage inventory and nameplate capacity may be calculated as negative numbers.
- Ensure that beginning of year inventory matches end of year inventory from previous year.
- Ensure that in addition to SF<sub>6</sub> purchased from bulk gas distributors, SF<sub>6</sub> purchased from Original Equipment Manufacturers (OEM) and SF<sub>6</sub> returned to the facility from off-site recycling are also accounted for among the total additions.

QA/QC methods should be employed throughout the year. Important checks/procedures include the following.

- Ensure that cylinders returned to the vendor are weighed in a consistent manner.
  - Gas suppliers measure the amount of gas remaining in cylinders/tanks returned (residual gas).
  - Gas suppliers can provide detailed monthly spreadsheet with exact residual gas amounts returned.
- Adopt practices such as tracking cylinders leaving and entering storage with check-out sheets and weigh-in procedures before the cylinders are put back into storage.
- Ensure all substations have provided information to the person responsible for compiling the emissions report (if it is not already handled through an electronic inventory system).

## 6. Reporting Procedures

The following supplemental data would be useful for confirming emissions calculations and/or calculating emission rates that could be compared across facilities for quality control purposes:

- Nameplate capacity:
  - Existing as of the beginning of the year.
  - New during the year.
  - Retired during the year.
- Transmission miles.
- SF<sub>6</sub> and PFC sales and purchases.
- SF<sub>6</sub> and PFC destruction.
- SF<sub>6</sub> and PFC recycled:
  - Sent offsite.
  - Returned from offsite.

## 7. References

EPA (2008) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*. U.S. Environmental Protection Agency, Washington, DC.

IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change, H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Hayama, Kanagawa, Japan.

RAND (2004) RAND Environmental Science and Policy Center, "Trends in SF<sub>6</sub> Sales and End-Use Applications: 1961-2003," Katie D. Smythe. *International Conference on SF<sub>6</sub> and the Environment: Emission Reduction Strategies*. Scottsdale, AZ. December 1-3, 2004.

UDI (2001) *2001 UDI Directory of Electric Power Producers and Distributors, 109<sup>th</sup> Edition*, Platts.